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VOL. 1

STEEL ALTERNATIVE GUIDEWAY STUDY
Phases I & II
FEASIBILITY REPORT

URBAN DOCUMENTATION CENTRE
RESEARCH UNIT FOR URBAN STUDIES
McMASTER UNIVERSITY
HAMILTON, ONTARIO

SEP 11 1981

HAMILTON-WENTWORTH RAPID TRANSIT PROJECT

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Metro Canada Limited
Hamilton-Wentworth Rapid Transit Project Office
Hamilton, Ontario

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STEEL ALTERNATIVE GUIDEWAY STUDY

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1. SUMMARY

The Regional Municipality of Hamilton-Wentworth currently has under consideration an Intermediate Capacity Transit System (ICTS) for a demonstration project in Hamilton. The ICTS, developed by the Urban Transporation Development Corporation (UTDC), consists of electrically powered trains travelling on a guideway system, which to date has been assumed to be constructed of concrete. The Hamilton-Wentworth Region has asked that the viability of steel as an alternative guideway material be investigated.

Metro Canada Limited (MCL), the Pre-Implementation Study managers, enlisted the assistance of ABAM Limited, Cole, Sherman & Associates Limited, and Wilson, Ihrig & Associates, Inc., in the areas of design criteria, structural analysis, and noise and vibration respectively. The study management, design review, risk assessment and environmental aspects were handled by MCL staff. The scope of the study included a limited literature search and design study, summarized in a feasibility report for one composite steel/concrete section. Each member of the study team prepared a report on their individual task, and this feasibility report combines and summarizes their findings.

The study's primary conclusion is that steel is in fact, a viable alternative material for the ICTS guideway. The specific section on which this conclusion is based is a composite steel/concrete trapezoidal box girder. It is further concluded that the alternative section can meet all of the criteria set for the concrete guideway, while remaining very cost competitive with concrete.

No adverse effects on subsystems were identified, and reassurances are given for some specific concerns, particularly noise transmission for which damping is recommended.

No complete solution is known for the staining caused by weathering steel, but some preventative measures are outlined.

For the final design phase further cross-section alternatives for the composite steel/concrete guideway should be considered together with other possible concrete alternatives.

The report recommends continued development of the steel guideway technology, so that a complete composite design capability is available for maximum versatility and economy. Several issues required further study, and a continuing effort is required to keep pace with the evolution of the ICTS technology.

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2. BACKGROUND

2.1 Introduction

A Pre-implementation Study is presently being undertaken by Metro Canada Limited (MCL) in the City of Hamilton to provide the Hamilton-Wentworth Regional Municipality with information on which to base a decision whether to proceed with installation of an Intermediate Capacity Transit System (ICTS) demonstration system. This study includes public participation activities, environmental assessment, alignment selection and a definition of requirements. The Pre-implementation Study, a one year program, is scheduled for completion in the fall of 1981, and is based on the ICTS system developed by the Urban Transportation Development Corporation (UTDC) for which a prototype system has been contructed and tested since August 1978 at the Transit Development Centre at Kingston, Ontario.

The ICTS system consists of compact, electrically-powered, steel wheeled trains which can run at grade, on elevated structures or on underground alignments where necessary. The guideway was designed as a lightweight structure to produce minimal visual intrusion in areas where it is elevated. Development of the ICTS guideway system by UTDC has proceeded rapidly based on a prestressed concrete superstructure.

At a meeting of the Technical Advisory Committee (TAC) held in December 1980, the Committee requested MCL to prepare a proposal for the analysis of a steel ICTS guideway in addition to the already contracted analysis of a concrete ICTS guideway. The scope of the study subsequently approved was to be limited to a literature search, a design study and a feasibility report.

This report contains the results of the steel alternative guideway feasibility study undertaken.

2.2 History and Development of ICTS

In April 1975, the Ministry of Transportation and Communications in Ontario authorized UTDC to proceed with a five-phase program to develop and test a

commercially viable, medium capacity transit system meeting user, community and operator requirements.

The operational design requirements for the ICTS were developed in conjunction with major transit operators and municipalities; system specifications and a preliminary system design were generated to meet those requirements. A prototype ICTS system has now been constructed and tested, entailing:

1. Construction of a prototype system test and demonstration facility
2. Development of subsystem technologies
3. Incorporation of the subsystem technologies into an integrated transit system prototype
4. Tests to assure achievement of system targets relating to safety, comfort, performance, noise and all-weather capability.

The prototype system has been undergoing tests since August 1978 at the Transit Development Centre.

2.3 Hamilton-Wentworth Rapid Transit Project

In 1978, the Ontario government proposed that Ottawa participate with it to install advanced rapid transit in Hamilton.

The project would provide a valuable transit service to the city and at the same time would demonstrate the new Intermediate Capacity Transit System technology developed by the Urban Transportation Development Corporation Ltd. Ontario further proposed that the estimated $70 million (1978 dollars) system be funded jointly with each government paying 45 percent of the cost and the municipality paying 10 percent.

The Hamilton-Wentworth Regional Transportation Committee and the Regional and City Councils endorsed the proposal, and a pre-implementation study for the Hamilton project is being conducted. This work, a one-year program, is being undertaken to provide the Municipality with information on which to base a decision whether to proceed with installation of the ICTS demonstration system. It includes public participation activities, environmental assessment, alignment selection and a definition of system requirements.

The Hamilton line would eventually connect the downtown central business districts with a residential and commercial section of the city on the Mountain. It would provide UTDC and a major transit operator with valuable experience in constructing and operating a passenger-carrying system, representing the first link in a Hamilton network. It would also make Hamilton a showcase for the world's most advanced urban transit technology.

Planning and evaluation activities are underway for installation of ICTS in Hamilton. The work is centred at the Hamilton Rapid Transit Project Office on Main Street and involves specialists from four levels of government plus industry, consulting firms and UTDC.

3. STEEL GUIDEWAY STUDY DEVELOPMENT

3.1 System Development

The major findings from the test program carried out at the Transit Development Centre indicated that all of the test program objectives can be met with a high degree of safety and reliability and that the I.C.T.S. has reached the stage of development where design and construction can proceed in specific urban centres.

3.2 Study Initiation

At the request of the Technical Advisory Committee, Metro Canada Ltd. presented a verbal proposal outlining a feasibility study for a steel guideway alternative. This proposal for a four-phased study is summarized as follows:

Phase I	-	Existing documentation compilation
Phase II	-	Design study and evaluation report
Phase III	-	a) Design development
		b) Alternate functional design for the approved alignment with a steel guideway design
Phase IV	-	Identifying and evaluating hybrid possiblities

The following study participants were suggested:

- Structural and Aesthetics - Cole, Sherman & Associates Limited and Trevor Garwood-Jones - Architects
- Noise and Vibration - Wilson Ihrig & Associates Inc.
- Design Criteria - ABAM Limited
- System Design and Management - Metro Canada Limited, Hamilton and Kingston

The following resolutions were made at the TAC meeting on January 8, 1981:

- Do not proceed with the study beyond Phase II. The revised proposal should include a literature search, a design study and a feasibility report only, generally as covered under the present Phases I and II

- Expenditures are to be limited to $100,000
- Proceed with, and submit a revised proposal to the TAC on January 28, 1981
- The sub-consultants proposed for the study and the management role by MCL were acceptable
- The concept of a hybrid guideway was acceptable.

Based on the above resolutions and taking into consideration the limited time and funding available for the study, the scope of work was reduced considerably by selecting one steel guideway section only for review and analysis. The selected guideway has basically the same cross-sectional outline as the presently proposed concrete guideway.

3.3 Guideway Development Program

Initial ICTS development selected prestressed concrete as the guideway material. This selection was based on a perception that prestressed concrete offered the optimum mix of the following factors:

a) Flexibility in design.
b) Generally competitive cost vis-a-vis other available materials.
c) Probability of meeting the low noise transmission and radiation characteristics essential to acceptance of ICTS in an urban environment.
d) Probability of meeting low vibration transmission characteristics required.
e) Perception that it would be aesthetically acceptable in a downtown core redevelopment program.
f) Perception that concrete structures, precast offsite, could be installed with minimum disruption of city traffic patterns and existing business activities.
g) Perception that offsite precasting of beams, crossheads and columns in variable geometry steel forms would provide significant cost savings.
h) Flexibility in construction in that cast in situ techniques could be used for special structures or small scale applications where precast production techniques were less appropriate.
i) Perception that the materials for prestressed concrete were more readily available at potential application sites on a worldwide basis.
j) Perception that tools and labour skills required for prestressed concrete construction could be more readily made available to potential application sites on a worldwide basis.

At the same time it was recognized that not all reasons for selecting concrete would be valid at all times in all places. In some locations other materials, and the tools and skilled labour to work them, are as readily or more readily available. In such locales the economics of the situation are much less clear. Techniques are potentially available that would permit other guideway materials, such as steel, to meet any or all the other criteria initially specified for the ICTS guideway. Again, the requirements for each application of ICTS are not written in stone, and some of the features of ICTS may have greater or lesser importance in a particular application. The perception of such subjectives as aesthetics and acceptability in the urban environment are a function of the specific urban setting as well as the eyes of the beholder.

It is against this background and in the above context that this study into the suitability of steel as a guideway material for the Hamilton-Wentworth ICTS application was undertaken.

3.4 Methodology

Study team responsibilities were finalized as follows:

(i)	Management, Literature Search, & Environment Considerations	- MCL (Hamilton)
(ii)	Systems Review	- MCL (Kingston)
(iii)	Information and Criteria	- ABAM
(iv)	Structural, Aesthetics and Feasibility Report writing	- Cole, Sherman
(v)	Noise and Vibration	- Wilson Ihrig

Meetings were held to define the work tasks for each of the participating organizations and work statements prepared as indicated in Appendix 8.7.

Each of the team members was requested to prepare a final report covering their part of the study tasks for inclusion as an appendix in the final feasibility report. This final report was also to include a summary documenting conclusions reached in the individual tasks.

These reports would be issued to all team members in draft form for comments and as input to ensure consistency between the individual reports. A final review would be held to correlate results and generate the feasibility report which would be written by MCL with assistance from Cole, Sherman & Associates Limited.

4. STUDY REPORT SUMMARIES

4.1 Literature Survey Summary - (See Appendix 8.1)
Metro Canada Limited

4.1.1 Introduction

The prime purpose of this review was to identify the relevant conclusions of earlier published works with a view to avoiding duplication of effort as much as possible. While there has been no attempt made to correlate the results of the studies, or rationalize differences, some points have been reinforced while other conflicting points obviously require a degree of rationalization, and indicate areas for possible further investigation. The highlights are discussed in Section 5.

Further, while all seven reports reviewed related directly or indirectly to elevated guideways of concrete or steel, there was some diversity of purpose and therefore varying applicability of report content. This summary is limited to those aspects concerning steel structures in general or composite concrete/steel guideways in particular.

4.1.2 General System Objectives

The available literature provides considerable information for use in the design of ICTS guideway systems in general, and guidelines for evaluating various concepts and materials. The most appropriate general comment at this time is that, in the development of guideway concepts, particular emphasis should be placed on lowering the total cost and minimizing the implementation time. Design activities and construction techniques that tend to reduce implementation time and/or cost are:

1) Off-site fabrication
2) Simplicity of design
3) Longer spans
4) Optimum integration of subsystems
5) Standardization
6) Modularity

4.1.3 Positive Features

The following conclusions reached in the previous studies tend to favour the use of steel in the subject application. The points are listed in decreasing order of reference:

a) The trapezoidal box girder section is considered the most acceptable visually, and the most appropriate for high quality urban integration
b) Steel box girder sections are appropriate for spans in the range of 120 to 170 ft., with the most economical simple spans being in the 120 to 140 ft. range
c) There are several methods of fabricating curved beams
d) The torsional stiffness of the composite trapezoidal box section is comparable to the concrete section
e) In a proper application, high strength steel is extremely cost effective
f) Tangent beam fabrication is very efficient and construction is simple and quick.

4.1.4 Negative Concerns

The following conclusions reached in the earier studies suggest further investigation and resolution, or a compromise, or act as a constraint in the application of steel.

a) Noise propagation
b) Maintenance and staining of surfaces below
c) Control system interference may be a problem
d) Appearance of weathering steel in the early stages of weathering
e) Noise and vibration damping adds to the cost
f) Fabricating curved girders results in waste material
g) Reliable field welding and bonding is required in a variety of environmental conditions
h) Field correction and adjustment of any misalignment is difficult (sic)

4.2 Structural Design Criteria Summary - (See Appendix 8.2)
ABAM Limited

The "Preliminary Structural Design Criteria for the Hamilton I.C.T.S. Transit System" prepared by ABAM Limited is a document of structural design criteria to be used by the structural designers exclusively for the development of steel guideway alternative designs. The main body of the document is design criteria extracted from the "Design Criteria and Commentary for the I.C.T.S. Guideway Structure", Revision C. Appendix A includes references and Appendix B presents a collection of rail structure interaction design examples taken from the ABAM report "The Design and Construction of the I.C.T.S. Test Centre Trackwork".

The structural design criteria for the Steel Alternative Guideway Study is outlined below:

Operational Requirements

Environmental Conditions
Vehicle Operation Performance
Guideway Performance Requirements

Structural Requirements

Loads and Forces
Vehicle Loads
Environmental Loads
Load Combinations
Strength and Serviceability

Trackwork Design

LIM Rail Design Parameters

Power Rail Design Parameters

Tolerances

4.3 Structural and Aesthetics Summary - (See Appendix 8.3)
Cole, Sherman & Associates Limited

This study has examined the viability of steel as an alternative guideway material to concrete from the viewpoint of structural adequacy and architectural appearance, the latter with the assistance of Trevor Garwood-Jones, Architects.

By agreement, only a trapezoidal composite concrete/steel box girder has been examined, in a two-span (30 m) continuous configuration. This box girder reflects the shape of the concrete box girder already developed. The foundation loads are almost identical to those generated with the concrete guideway, and it has been assumed that the choice of guideway material will not affect foundation feasibility or cost.

The design of the steel box girder and column-crosshead meets the major requirements of the Design Criteria prepared by ABAM Limited for the study, utilizing analyses aided by the MTC computer programs. The basic comfort criteria required for the ICTS system have been met. Allowance has been made in the dead loads for possible sound damping materials.

Greater emphasis has been placed, in the study, on those guideway elements in which steel appeared to be most attractive as an alternate guideway material. Thus, more effort has been expended in examining tangent sections and large radius bends than on other elements, although the examination of the other elements in steel has been taken far enough to establish viability.

The implications of incorporating conduits, a deck drainage system and permanent or temporary bracing have been considered in the designs, and vertical construction tolerances have been compared for both concrete and steel. A cursory examination of the possible effects of stray DC current has been included.

The architectural impact of the guideway using weathering steel as the girder material has been considered, together with the associated precautions to be taken.

Comparisons have been made between the concrete guideway and steel alternative on the basis of cost, supply and delivery, and constructibility.

Constructibility has been investigated with particular reference to construction time and urban impact resulting from construction.

A total guideway cost has been calculated for each material based on a hypothetical but representative Hamilton alignment.

While further study is recommended on several items, some of the main study conclusions are:

1. The composite steel/concrete trapezoidal box section girder is clearly a viable alternative to a concrete box girder in the Hamilton ICTS guideway system.
2. The strength, cost, feasibility, aesthetic, rider comfort and noise radiation standards set by the ICTS system can be met by the steel alternative guideway system to the same degree as the concrete guideway system.
3. Weathering steel, as an architectural material, offers a distinctly different appearance to that of concrete, particularly at close range. However, colour may have only a marginal visual impact, as compared with the impact of the guideway mass as a whole. The slightly reduced beam depth and smaller circular-section columns of the composite guideway offer some reduction in visual impact over the concrete alternative.

4.4 Noise and Vibration Summary - (See Appendix 8.4)
Wilson Ihrig & Associates Inc.

Compared with other transit vehicles in use today, the ICTS vehicles proposed for Hamilton are considerably lighter (21,000 kg @ crush capacity) and operate at much slower speeds (72 km/hr cruise speed). Consequently the wayside noise from the ICTS system is, in general, significantly less than that associated with other transit systems.

The Region of Hamilton-Wentworth has expressed a desire to investigate the feasibility of steel in construction of the elevated guideway as an alternative to an all-concrete structure. However, based on existing experience in the transit industry, the use of undamped steel plates as part of the composite steel/concrete elevated structures can result in community noise levels due to train pass-bys that are potentially unacceptable. An analysis was made to determine the comparative wayside noise levels of trains operating on three alternative elevated guideway designs and the relative impact on the wayside community. The three designs are damped and undamped steel, and concrete.

Based on measured noise and vibration data taken by Metro Canada at the ICTS Transit Development Centre in Kingston, Ontario, and a prediction model derived from a combination of empirical data and theoretical analysis, noise levels due to train pass-bys have been projected for the composite steel/concrete guideway with and without damping. These were compared with the measured data obtained at the Transit Development Centre which has an all-concrete elevated guideway.

The proposed Hamilton ICTS will be routed through three basically different areas of the city: Central Business District (CBD), Escarpment, and Mountain. Each of these areas has a unique existing noise environment and requirement that should be taken into consideration. An assessment of the impact of wayside noise on the community in the three areas was made using the predicted wayside noise determined by this analysis for the three alternative elevated

guideways. To determine comparisons of the predicted wayside noise the resulting interior noise in typically constructed buildings was determined for typical train pass-bys.

The general conclusions that can be drawn from this study are:

(1) Even with the expected higher levels of structural noise radiation, the noise actually radiated from the wheel/rail interaction and the transit cars is expected to dominate the A-weighted wayside noise levels from normal operations on both the concrete and steel/concrete composite ICTS structures, at least for outdoor noise.

(2) With the use of constrained layer damping treatment applied to the steel plates, the ICTS steel/concrete composite structure is expected to provide essentially the same performance regarding wayside noise as the all-concrete structure.

(3) The outdoor A-weighted noise levels are not expected to differ significantly with either the concrete, undamped composite, or damped composite elevated guideway.

(4) In the CBD, unless there is now or should be in the future an area with significant number of lightweight residential structures (as contrasted to high-rise masonry structures), there will not be any significant difference in noise impact from the three types of elevated guideway.

(5) In the Escarpment area the noise impact will also be essentially the same with any of the three types of guideway, because this area is primarily open space. However, if there are any lightweight residential type buildings located near the guideway in this area, the undamped steel/concrete composite guideway would result in greater interior noise levels at low frequencies, and for such conditions damping should be used.

(6) In the Mountain Region, either the all-concrete or damped (using constrained layer damping) steel/concrete composite guideway would result in the same noise impact. However, the high levels of low frequency rumble noise from the undamped steel structure will result in a significantly

increased impact inside buildings compared with the other two alternative guideways. Only in areas where there is a very high volume of night time commercial traffic present would it be possible to use the undamped composite structure. The evaluation of those areas for which the steel requires damping should include consideration both of the first and second row of houses near the guideway structure.

(7) A cost estimate using presently available data for the purchase and installation of constrained layer damping is $210/m per single lane guideway beam. This assumes a 37% area coverage of the steel plates in the guideway, a typical figure for such damping applications.

4.5 Environmental Review Summary - (See Appendix 8.5)
Metro Canada Limited

In Task E-1 of the Pre-Implementation Program, information was documented on the existing bio-physical conditions in the study corridor. The following list of bio-physical parameters were utilized as a basis for comparing the differences in environmental impacts between a composite steel guideway and a concrete guideway structural form. The differences are listed beside each parameter.

Air Quality	-	minor differences
Climatic Factors	-	minor differences
Wildlife	-	no difference
Hydrology	-	no difference
Topography	-	no difference
Geology	-	no difference
Vegetation	-	no difference
Construction Impact	-	minor differences

In summary, there is no evidence that suggests a composite steel guideway structure would have more impact on the natural environment than a reinforced concrete guideway structure.

4.6 Design and Risk Assessment Summary - (See Appendix 8.6)
Metro Canada Limited

A study has been carried out by a team of consultants reporting to Metro Canada Limited in Hamilton to provide inputs to a feasibility report on a steel, or composite steel and concrete, guideway for ICTS.

Metro Canada Limited in Kingston was tasked with identifying any interface problems between the steel guideway and the guideway mounted subsystems and to carry out a risk assessment, based on in-house data and the inputs of the other participants to this study.

As a result of this activity no significant technical problems were identified in the integration of the guideway mounted subsystems with the proposed composite steel beam and concrete deck guideway.

A number of potential problem areas were shown to be solvable. This left only two areas for which the solutions will not be entirely technical. These are the areas of aesthetics and costs.

Aesthetic problems are the staining of adjacent concrete structures with oxides washing off the weathering steel, and a perception that a weathering steel guideway will not harmonize with the concrete, masonry and glass of the Central Business District. The degree of acceptability of a weathering steel guideway is directly related to satisfactory solutions to these problems.

Comparative cost estimates (Appendix 8.3) indicate an advantage for the steel composite guideway. It is felt that a more in-depth study is required in each locality to obtain comparative cost data. Until firmer cost data is thus available the achievability of the predicted guideway economies is open to question.

5. DISCUSSION

5.1 General

There is a considerable amount of technical information available on the use of steel for guideways. The most pertinent reports form the appendices to this feasibility study, prepared by the individual study team members. While all past and current studies have had a degree of commonality, with their specialized individual concerns it is to be expected that there will be differences of opinion as well as areas of consensus. In this section we will identify the basic common conclusions and try to understand the apparent disparities.

It should be emphasized that this is a sub-study of the main Pre-Implementation Study for the Hamilton-Wentworth Region, and as such does not deal with matters relating to the main study, or that are common to both steel and concrete systems. It should further be noted that while this study is specifically for the Hamilton-Wentworth system, much of the information contained herein (other than costs) could be applied in other locations.

This entire study has been based on the most current information available. However, as the entire system is still under develoment, changes in the base data can be expected.

5.2 Structural Adequacy

There is virtual unanimity in the acceptance of a composite steel/concrete box as a structurally competent cost competitive alternative to the reinforced concrete box.

The capability for longer spans than the standard length used for the concrete is confirmed; however, the increased span length is limited by the desire to keep the box depth the same as the concrete depth. The torsional stiffness and fabrication efficiency have been confirmed in the current study.

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5.3 Appearance

There are those who find the appearance of the weathering steel to be quite acceptable; while others contend that the different appearance of weathered steel is marginally negative but in some settings may be more suitable than concrete. Obviously the perception is largely a matter of personal judgment. It is fairly evident however, that the suitability of both steel and concrete is greatly influenced by the surroundings in which they are to be placed.

It is noted that the weathering steel is least attractive in the very early stages of weathering and measures to accelerate weathering are being studied. It should be noted that the Hamilton atmosphere is particularly conducive to weathering.

There is general agreement that the trapezoidal shape is aesthetically the most pleasing. It is worth noting, however, that the difference between a slope-sided and a rectangular box may not be discernable to the majority of viewers. A cost saving would result from the use of the rectangular shape on tangent sections. The saving would be significant for curved sections.

5.4 Staining

The staining caused by waterborne rusting is generally acknowledged to be a significant problem in an urban environment. Several means have been discussed to minimize both the amount of, and the effects of staining; however, the fact remains that there is as yet no guaranteed means of eliminating the problem. In this study, it has been presumed that the effects of staining would be alleviated by the use of steel columns. In those rare circumstances in which no amount of staining is tolerable, it is suggested that weathering steel not be used. It is noteworthy that research is continuing in search of an acceptable solution to this problem, including the development of much-improved paint coatings.

5.5 Noise

The most common concern about the use of steel in guideways is the radiation of noise. While there have been expressions of concern in the Design and Risk Assessment, Wilson, Ihrig & Assoc. have determined that the ICTS is quieter than other systems and that most of the noise is airborne rather than through the structures. It is acknowledged, however, that in some locations, some damping is required to maintain the same performance as the concrete guideway. Cost estimates have, therefore, included damping throughout.

5.6 Construction

The reported difficulty of field correction and adjustment of any mis-alignment is unlikely to arise. However, the structural consultants believe that, as with precast concrete, proper control measures during the design and construction stage can minimize potential problems without adding any major cost.

6. CONCLUSIONS

6.1 The composite steel/concrete trapezoidal box section girder is clearly a viable alternative to a concrete box girder in the Hamilton ICTS guideway system.

6.2 The strength, cost, feasibility, aesthetic, rider comfort and noise radiation standards set by the ICTS system can be met by the steel alternative guideway system to the same degree as the concrete guideway system.

6.3 Weathering steel, as an architectural material, offers a distinctly different appearance to that of concrete, particularly at close range. However, colour may have only a marginal visual impact, as compared with the impact of the guideway mass as a whole. The slightly reduced beam depth and smaller circular section columns of the composite guideway offer some reduction in visual impact over the concrete alternative.

6.4 Careful design minimizes the potential staining caused by the use of weathering steel.

6.5 Even with the expected higher levels of structural noise radiation, the noise actually radiated from the wheel/rail interaction and the transit cars is expected to dominate the A-weighted wayside noise levels from normal operations on both the concrete and steel/concrete composite Hamilton ICTS structures, at least for outdoor noise.

6.6 With the use of constrained layer damping treatment applied to the steel plates, the Hamilton ICTS steel/concrete composite structure is expected to provide essentially the same performance regarding wayside noise as the all-concrete structure.

6.7 The outdoor A-weighted (perceived) noise levels are not expected to differ significantly with either the concrete, undamped composite, or damped composite elevated guideway.

6.8 There is no evidence that suggests a composite steel guideway structure would have more impact on the natural environment than a reinforced concrete guideway structure.

6.9 The composite guideway offers the advantages of added flexibility in alignment geometry and reduced urban impact due to its lighter weight and longer span capability.

6.10 In order to provide a fully competitive steel alternative design some minor technical issues require resolution.

7. RECOMMENDATIONS

The foregoing series of conclusions lead naturally, to the overall conclusion that the composite steel/concrete guideway designs ought to be developed in parallel with the concrete guideway designs. It is therefore, recommended that:

7.1 Any consideration of tender documents should include development of optimum designs and construction logistics to the same level of detail for both concrete and composite alternatives.

7.2 Local identification with the use of steel as a guideway material be reinforced by adding the composite steel/concrete guideway alternative to the work remaining in the Pre-Implementation Study, assuming that a parallel composite guideway technology development is undertaken by U.T.D.C

7.3 As part of the final design process, guidelines be established for hybridization for the selected alignment, to utilize the composite and concrete alternatives to best advantage.

7.4 Significant new information obtained from ongoing studies and tests be forwarded to the Technical Advisory Committee and the Steering Committee as it becomes available.